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Sustainability Science and Implementing the Sustainable Development Goals

Integrated urban water management scenario modeling for sustainable water governance in Kathmandu Valley, Nepal

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Abstract The goal of ensuring water availability and sustainable management of water for all by 2030 is one of the top priorities of the UN-SDGs. The fragile institutional capabilities induce the transitioning towards the sustainable urban water paradigm to accommodate the complexities and uncertainties. This research methodically draws sustainable water management strategies to achieve water security after a critical literature review, trends and policy analysis, and scenario modeling of the study area. First, research systematically illustrated the analysis of unmet water demand and coverage during the study period (2015–2030) and evaluated the impact of external factors such as population growth, living standard, and climate change on the current water system of the Kathmandu Valley. The results showed that future water demand is likely to reach 765 MLD by the year 2030 from the estimated current demand of 388.1 MLD. Also, external factors will increase the pressure on the current water supply–demand systems, and hence exacerbate the water stress but result showed the negligible impact of climate change during the study period. The research explored the significance of "Melamchi Water Supply Project (MWSP)" and found that the effective implementation of MWSP will decrease the unmet water demand by 56–66% in the valley. In the second part, comparative analysis of different management strategies under four future scenarios (optimistic, moderate I and II and business-as-usual) were carried out. The comparative analysis revealed that the proposed optimal management strategy (under optimistic scenario) would lead to achieving 100% of water demand coverage by year 2027.

Keywords Sustainable development goals · Water security · Climate change adaptation · Sustainable water governance · Melamchi Water Supply Project

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Introduction

Water has social and economical value for humans and it is a vital natural resource for physiological processes of all organisms on the planet. Many regions critically lack access to safe water although clean drinking water and sanitation is considered the basic right of everyone. Water system management should provide clean and safe water for a variety of use without impacting the environment. The rapid population growth and economic development put constant pressure on the ecosystems of water resources (Flato et al. 2013; Hanemann 2006; Alcamo et al. 2007). There is a strong correlation between water consumption and urbanization as consumption rate greatly depends on the pace of urbanization, population growth and economic activities (Bao and He 2015, Saraswat et al. 2016). Cities, in particular, emerge and grow accompanying population growth and economic activities ultimately putting stress on the available water resources (Haddeland et al. 2014, Bhave et al. 2016). The increasing water demands in cities have put pressure on all kinds of available water infrastructures in an unprecedented way (Hellström et al. 2000). These stresses have caused decrease in the per capita usage to a water scarcity level and also resulted in the degradation of the water quality in many countries (Al Radif 1999). Therefore, the sustainable management of water is an utmost priority and significant in achieving the sustainable development in rapidly urbanizing cities. For the similar reasons, interrelated and interdependent United Nation's Sustainable Development Goals (SDGs) focus on various water issues to achieve human wellbeing and healthy ecosystem (UN-Water 2015; Harlin and Kjellén 2015). It is analyzed that goal 6, water for all and sanitation, is critically significant in accomplishing the desired results by 2030.

Water scarcity is a situation when water demands grow beyond water supply, because of its physical availability or unorganized development and insufficient infrastructure. There are several interrelated causes of water scarcity (Hoekstra et al. 2012; Abrams 2009) affecting most of the countries. Currently, more than 16% of world population lack access to safe drinkable water. Every year, nearly 38% of world population at least faces 1-month water scarcity situation. In the South Asian region, where more than 22% of the world population resides, the urban areas are increasingly feeling the urbanization, population growth and impact of climate change in the form of high unpredictability and seasonal water scarcity. It is estimated that 22 of 32 Indian cities face daily water shortages (Vairavamoorthy et al. 2008). In the capital of Nepal, Kathmandu, local residents have to wait in queues for hours to obtain drinking water from the stone waterspouts in the city and in the Pakistan, water scarcity has led to citywide protests (Akhtar 2016). To reorient the growing urban agglomeration towards the sustainable water management, different characteristics of urban water should be viewed. This requires the adoption of a comprehensive approach to urban water system analysis, design, and management. Integrated urban water management (IUWM) takes an inclusive approach to urban water services, water supply, and demand, mechanism of the physical system and distinguishes that the physical system lies within governance structure or organizational framework (Mitchell 2006; Grigg 1997). This study considers the IUWM, as the suitable approach for solving water shortages, water demand–supply and governance issues of rapidly growing urban agglomeration such as Kathmandu Valley, Nepal. Along with IUWM, the research brings the scenario modeling to analyze and validate the effectiveness of management strategies based on principles of IUWM and sustainable water governance in the city. The IUWM principles consider the water cycle as an integrated system, water requirements for humans and ecosystem, from local to the global context, stakeholders and strive for sustainability (Butler et al. 2014; Burn et al. 2012).

The research places emphasis on demand-side management as well as supply-side management, utilization of nonconventional water resource with the concept of water harvesting, and sustainable institutional arrangements as an important element of sustainable urban water management unlike the past, where water resource management was an exercise of engineering consideration. This approach brings the various factors such as individuals and organizations with different interests and options, together (Hamlat et al. 2013; Yates et al. 2005). The approach requires the analysis of the application of effective integrated urban water management principles into a model that can solve the encountering multifaceted water problems (Granit et al. 2013; Hack 2013). In the study, water evaluation and planning (WEAP) model, which can incorporate and operate the hydrological parameters and management processes at the same time, and able to model the different management options is identified as the required tool (Yates et al. 2005). The WEAP model is preferred over other models because of its usefulness in analyzing the designed strategies and scenarios based on 'What-If' conditions. The WEAP model is able to simulate a set of scenarios based on monthly time steps for any period from single year to more than 100 years (SEI 2015). The model is efficient in modeling and analyzing various factors such as water supply–demand, quality, allocation priorities, groundwater, streamflow, reservoir operations, energy demands and ecosystem requirements (SEI 2015). The model is widely documented in various literature, as an efficient modeling tool in effective analysis of urban water management issues such as reduction in water demands, increase in water recycling and reuse, identification of alternative water supply sources, stormwater use, rainwater harvesting and study of water resources as one system (O'Connor et al. 2010; Droogers et al. 2008). Applications of WEAP model in designing and analyzing the water management scenarios options such as individual saving water with three options of 10, 20, and 30% for diverse climatic situations in the subbasin of the Olifants River in South Africa (Lévite et al. 2003) and in assessing the future water demands in the Niger River (Mounir et al. 2011) are able to prove the usability and credibility of model for the purpose of scenario modeling in the study.

Based on IUWM principles, first, this research systematically illustrated the analysis of unmet water demand and total demand coverage during the study period (2015–2030) using WEAP model to understand the impact of external factors (population growth, living standard, and climate change) on the current water supply system. At the later stage, the study designed the management strategies to evaluate the effective strategies using scenario modeling. Various management strategies were based on four different future scenarios (optimistic, moderate I and II and business-as-usual) to compare unmet water demands by the year 2030.

Study area

Kathmandu Valley, the capital of Nepal, covers an area of 595 km^2. It is the political, economic, and cultural hub as well as the largest populous city in the country. The valley has moderate temperature throughout the year having the average maximum temperature of 25.7 °C and the average minimum of 11.4 °C. The rainfall in the valley is substantial varying from 1000 to 1600 mm per year with a mean annual value of 1540 mm and maximum annual value of 5200 mm. The rainfall is unevenly distributed with heavy concentrations from June to September during the monsoon season and the mean (Mohanty 2011; Jha and Shrestha 2013). With an annual growth rate of 4.63% (KVDA 2011; KVDA 2014; CBS 2014), it is estimated that the current population of the Kathmandu Valley is 2.9 million from 0.41 million in year 1952/1954 (Table 1). The rapid population growth and urbanization greatly increased the water demand of Kathmandu Valley (Shrestha et al. 2015). The valley encloses the entire area of Bhaktapur district, 85% of Kathmandu district and 50% of Lalitpur district (Fig. 1). The valley is bowl shaped and surrounded by the Mahabharat mountain range on all sides (Pant and Dangol 2009; Portnov et al. 2007; HMGN/MFSC 2002). Three major river systems in the valley are the Bagmati, Bishnumati, and Manohara.

Assessment of current situation of water demands

With the increase in population, the water demand is also increasing, but the supply is not increasing significantly, which results in acute water shortage. Considering various factors (population, per capita consumption) and conditions in the WEAP model, the study estimated current water demand of 388.10 MLD (0.38 MCM/day). This is in line with earlier studies which estimated the current water demand in the range of 350–400 million liters per day (MLD). As shown in Fig. 2, the problems are chronic water shortage and unsustainable due to lack of adequate water supply and others. Due to the factors shown in Fig. 2, the situation of water stress in the Kathmandu Valley is increasing.It is estimated that the important causing water stress in the valley is a lack of sustainable water governance in the region.The main authority responsible for supplying water in the valley is Kathmandu Upatyaka Khanepani Limited (KUKL), currently able to supply water by using 35 surface sources, 59 operating deep tube wells, 47 ground reservoirs and 39 pumping stations with 21 functioning treatment plant of around 117 MLD capacity (KUKLPID 2015, IUCN Nepal 2013). Currently, the water demand is partially met by the supply, with only 88.8 MLD (33% by groundwater and 67% by surface water) in the dry season and 118.4 MLD (29% by groundwater and 71% by surface) in the wet season (Subedi et al. 2013). In other words, there is a water deficit of 78.5% in dry season and 63% in a wet season. According to Pandey et al. 2013), KUKL produces 70% of supply from groundwater sources. It is estimated that non-accountable water or non-revenue water (NRW) is high as 35–40% due to inadequate water infrastructure and losses in existing water distribution systems (KUKL 2011, ICIMOD 2014). Table 2, the performance indicator of water supply in major Asian cities, shows that NRW in the Kathmandu is very high in the region. Inadequate water supply and losses from KUKL causing the population to depend upon groundwater resources in the valley, which is causing the unsustainable abstraction of groundwater as well as overdependence on alternative sources of water such as traditional spouts, tube wells, and private water tankers. The literature review revealed that more than 2/3rd of total household in the valley have private wells and use the groundwater despite having piped water connection (Shrestha et al. 2015; Yoden 2012, Jha 2012), which results in extraction of groundwater more than twice the natural recharge rate in the valley (Shrestha et al. 2015).

Realizing acute water shortage problems in the capital city, Government of Nepal (GoN) launched a project called "Melamchi Water Supply Project (MWSP)", an inter-basin water transfer project, with funding from Asian Development Bank (ADB). The MWSP is aimed at augmenting 510 MLD in three phases from the neighboring river basins to water-scarce Kathmandu Valley (Shrestha et al. 2015). The project is still under construction and planned to supply water to Kathmandu Valley from the year 2017

Table 1 Population trend of Kathmandu Valley analyzed from CBS 2014)

Year	Population (million)	Pop. growth rate (%)	Remark
1953	0.20	1.65	Expansion in 1930–1940
1961	0.22	2.07	Expansion in 1950
1971	0.61		Expansion 1965 and 1973
1981	0.77		Expansion in 1983
1991	1.11	3.84	Expansion in 1991
2001	1.25	4.06	Expansion in 2003
2011	1.65	4.63	–

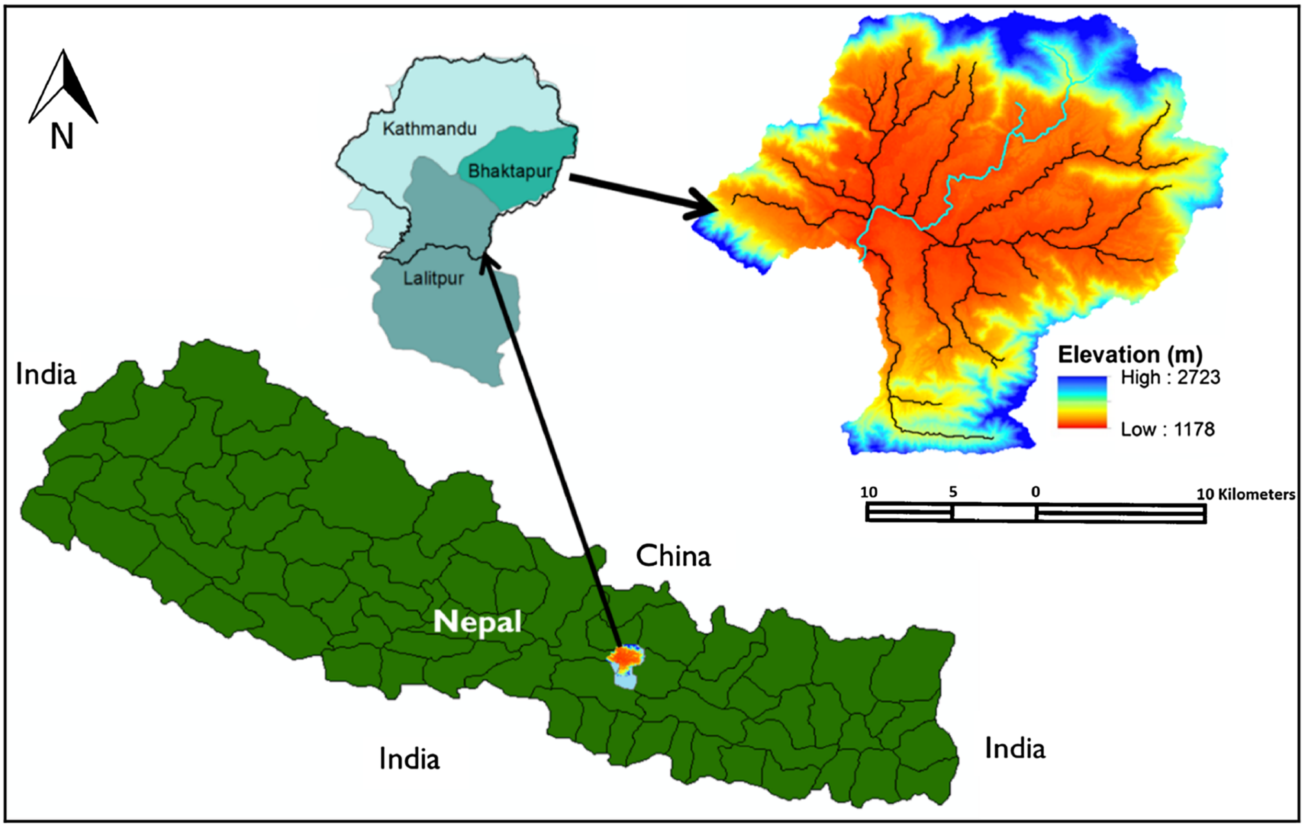

Fig. 1 Study area (Kathmandu Valley, Nepal) map with river system

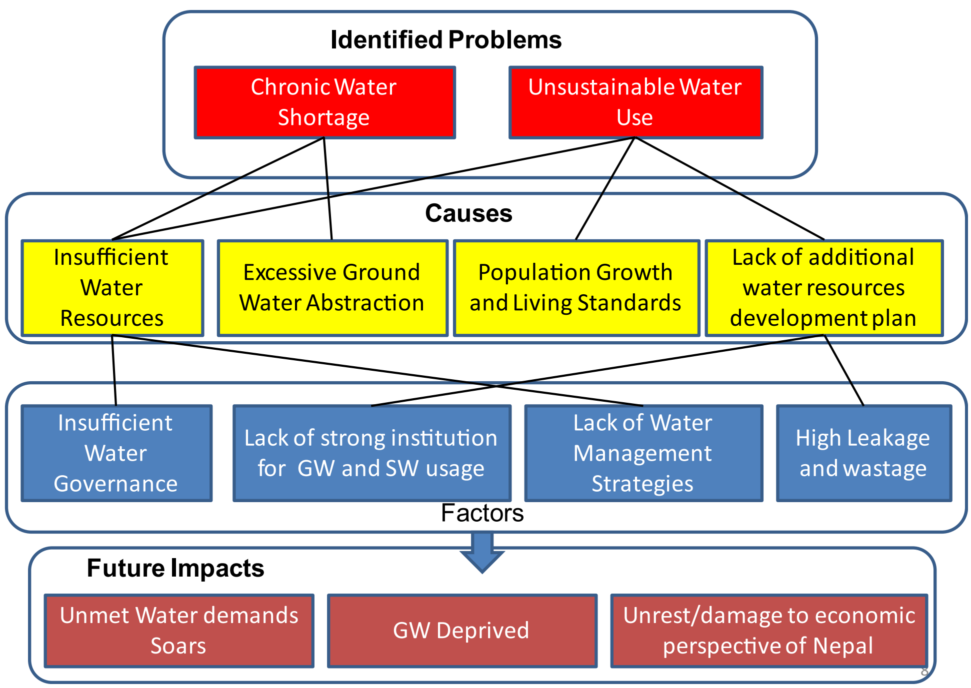

Fig. 2 Identified problems, causes, factors associated and impacts on water resources management in Kathmandu Valley

(KUKLPID 2015). While modeling the impact of MWSP, the authors consulted KUKL officials, analyzed the master plan, and ADB reports. Therefore, all the scenario modeling for the study is based on the most likely timelines of different phases of Melamchi Water Supply Project. The consultations and reports pointed out that MWSP will be delivered in

Table 2 Performance indicators of water supply service in urban region of Asia (adapted from JICA 2014)

Country	Indonesia	Thailand	Vietnam	Malaysia	Nepal	Singapore
City	Jakarta	Bangkok	HMC	Kuala Lumpur	Kathmandu	Singapore
Pop. (million)	8.70	7.96	5.97	1.49	2.80	4.73
Coverage (%)	62.00	93.00	84.00	100.00	21.00	100.00
Water use rate (Lpcd)	95.00	140.00	121.00	314.00	135.00	220.00
NRW (%)	50.00	29.00	41.00	35.00	35.00–40.00	4.00
Year	2008	2009	2009	2008	2015	2009

three phases with 170 MLD each by 2017, 2022 and 2027 (Bhattarai et al. 2005; MWSP 2015). Finally, along with MWSP, impacts of population growth, urbanization and climate change future water demands were assessed to achieve a water-secure future using principles of IUWM.

Materials and methods

Data collection and analysis

Figure 3 provides the overall research methodology applied in the research. A mix of qualitative and quantitative research approach was used to acquire the in-depth understanding of current water governance mode and water supply system of Kathmandu Valley. To address the goals of the study, the twofold approach is applied, which build on management and political science literature. From the management literature, the water demand–supply analysis, formulation of scenario based on supply- and demand-side management and the principle of strategies formulation and evaluation of their effectiveness are employed to cope up with water stress in the valley in a different timeline. From the political science literature, water institution arrangement analysis and theory of sustainable water governance were studied. The triangulation of research methods such as case study interviews, informal observations and engaging water experts are applied to achieve the result

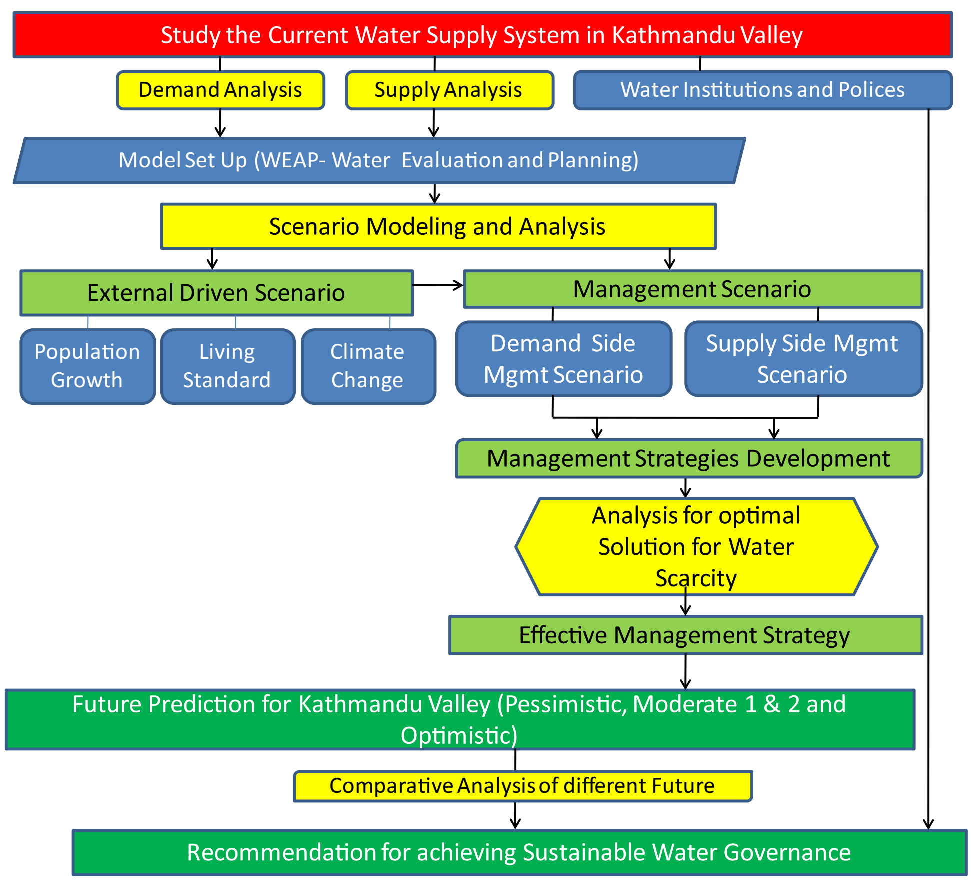

Fig. 3 Research methodology for IUWM scenario modeling of Kathmandu Valley, Nepal

applied along with secondary data collection of past experiences, semi-structured interviews, documentary information and archive records. The data gathered using survey, focus group and expert interviews of KUKL and key stakeholder involved interviewed. Also, this comprises the narrative analysis drawing from interviews with key government officials, KUKL official, NGOs, and international lenders (ADB) as well as focus groups with targeted communities in the valley.

The interviewees are differentiated between primary (managerial positions) as well as secondary and the questions are semi-structured addressing the potential of dynamic capabilities, role, and means of research and development, investment priorities, restructuring, future trajectories of the utilities and the water sector.

Model setup

In the WEAP model, the existing water supply system of Kathmandu Valley is represented and evaluated based on current and different future scenarios, taking into account the associated factors and policies that affect demand and supply sources in the valley (shown in Fig. 4). The model is capable of simulating water supply system operations on valley level on a user-defined time step. The water mass balance is computed for the demand site (represented by red dot, whole city as one), water flows in the catchment region. The components of the water system links of for the simulation period to forecast the water development and management scenarios (Hamlat et al. 2013; SEI 2015; SEI 2011; McCartney and Arranz 2007). Due to the complexity of the valley water system, the model is set up to represent Kathmandu as one system, with one demand node, one valley-level catchment and six infiltration links connecting one reservoir, one virtual reservoir representing the rainwater harvesting, one groundwater source, only one surface water source representing the rivers. First, to create the study area on WEAP, the vector layer is added as a background map adapting the geographic coordinate system with the model. The time steps per year are used with a calendar month, starting from January and adding leap year, current account year (current scenario) is set as 2015 and future scenarios in a period of next 15 years. The step is followed by input the data for demand sites, such as annual activity level, population growth, monthly variations, loss rate and consumptions level. In this model, all losses from the whole system, i.e., NRW amount 35–40% (KUKL 2015), will represent with transmission losses in transmission links because of the lack of data for different losses.

Demand site management savings (DSM savings) represents the percent of reduction from the total monthly demand due to the various demand-side management strategies, such as using water-saving technology, using the block-rate water pricing (WEAP 2014; WEAP 2015; SEI 2015) is set to 20% (KUKL 2015). The water supply data

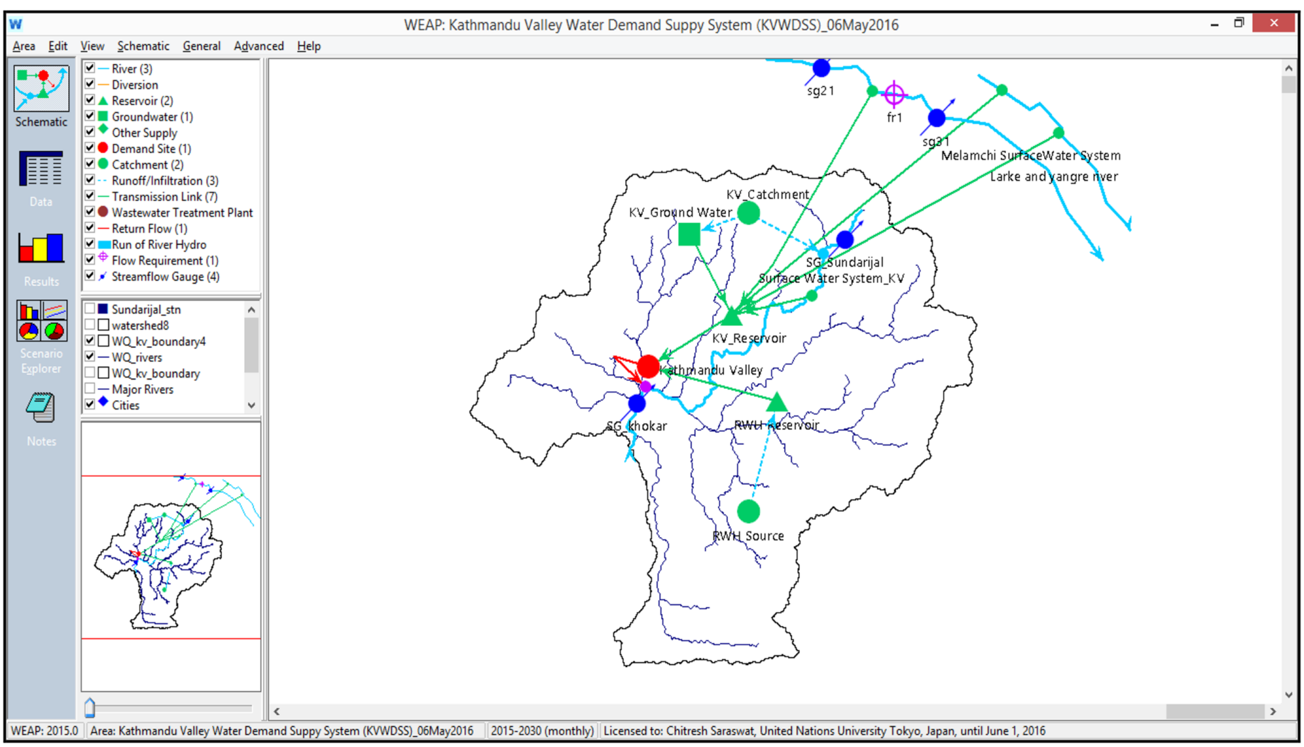

Fig. 4 Schematic representation of WEAP model of water demand–supply system in Kathmandu Valley

from various sources including KUKL were used for setting up the WEAP model. The WEAP model is not limited to simulate only human behavior for changes in demand, but also to simulate physical processes of the water sources and facilities. The studies used for management, proposes that the total volume errors below 10% are very good, between 10 and 20% is good, and between 20 and 30% is fair (Ingol-Blanco and McKinney 2009), and is applicable to the study. The performance of the WEAP simulation is verified both at demand and supply side. At the supply side, the results of demand side are applied in the analysis of model performance (Immerzeel and Droogers 2008). It is estimated that in the year 2015, in Kathmandu Valley, the average supply delivered in the city are around 75.5 MLD and the average demand coverage was about 17–25% using WEAP model. These data are nearly the same (less than 10% deviation) as the observed value for demand coverage is 25–34% and average supply delivered, 90 MLD, which was calculated based on primary and secondary data analysis and discussion with KUKL water utility officials.

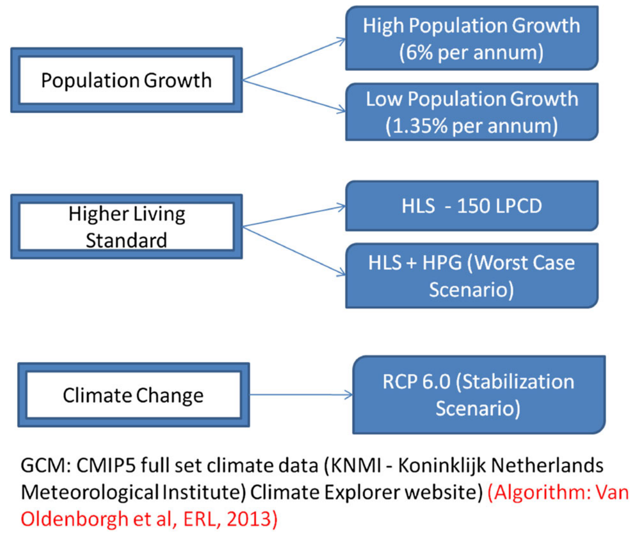

Fig. 5 Schematic of the design of external-driven factors scenario for Kathmandu Valley

Formulation of scenarios and management strategies

In the WEAP model, scenario analysis is performed based on "What-If" question and analyzed by comparing the business-as-usual/reference scenario against the actual data for the understanding of current trends and other scenarios with changes on both demand and supply sides (WEAP 2014; WEAP 2015; SEI 2015). In the research, various scenarios relating the external changes and different management alternatives are developed to analyze the impact on current water supply and evaluate the future water supply options in Kathmandu Valley. The first, reference scenario was built, representing the current situation of the urban water supply system, which worked as a reference point in evaluation and analysis further.

To understand better the impact of external factors on the future water supply system of Kathmandu Valley, future scenarios are simulated based on socioeconomic changes such as high population growth (HPL) with the rate of 6% per annum (KVDA 2015), low population growth (LPG) with the rate of 1.35% per annum (CBS 2011), and changes in living standard of residents due to economic growth in city, HSL with estimated changes of 135 L per capita (Lpcd) to 150 Lpcd by year 2030 (Fig. 5). The climate change can confound water resources planning because of its uncertain effects and difficult prediction (Conway 2009; Mounir et al. 2011). A study in New York City has shown that the daily per capita water use increases by 19 L for every 1 °C increase in temperature (Protopapas et al. 2000). For the analysis of climate change effect on future water supply in Kathmandu Valley, the climate change (CC) scenario is constructed by using the climate data acquired using the downloaded Global Climate Model data set of the Coupled Model Intercomparison Project, Phase 5 (GCM: CMIP5 full set) from KNMI (Koninklijk Netherlands Meteorological Institute) climate explorer website. The GCM CMIP5 (full set) includes multiple realizations of each model, down weighed to be the same weight for each model and there are four representative concentration pathways (RCPs), such as RCP2.6, RCP4.5, RCP6.0, and RCP8.5. For the purpose, RCP 6.0 stabilization scenario is preferred because of the study period time length and fit in purpose to understand the aspect, it is a medium path.

The study aims to design the effective strategies to achieve water security in the Kathmandu Valley. After analysis of externally driven scenarios, the strategies build based on current and future available resources and tested. To design the demand and supply management scenarios; demand and supply side strategies are modeled in WEAP model and evaluated using what-if conditions. The demand-side management scenarios (DSM) are divided, based on two strategies, one is changes in water pricing policy (DSM-WPP) (Renzetti 2000) and the other is the introduction of new sustainable water sources such as rainwater harvesting and reuse (DSM-SWS) (Fig. 6). Similarly, two strategies are selected to construct scenarios for supply-side management (SSM) as well, the biggest problem in current water supply identified was NRW, after consulting master plan, the introduction of the NRW control plan the supply would be managed more effectively (SSM-NRW), which is to reduce NRW from 35–40% in 2015 to 20% by 2030 (Fig. 6) and another one is the

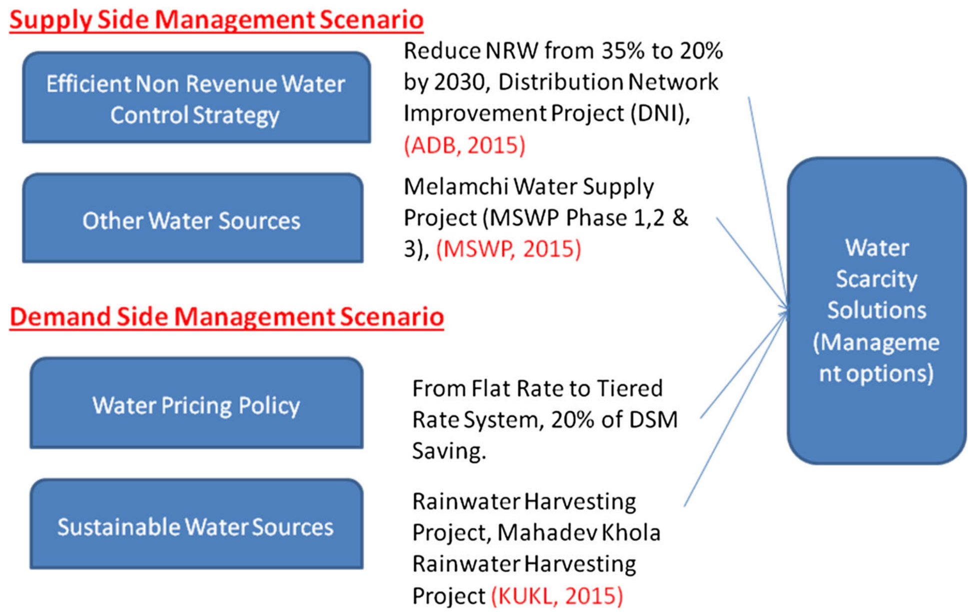

Fig. 6 The management scenarios formulation to attain water security in Kathmandu Valley

develop new sources of supply to add on current water supply, one scenario is built on considering Melamchi WSP as an alternative source of water supply (SSM-OWS) for Kathmandu Valley (MWSP 2015), was explained in detail in study area section in the paper. The SSM-OWS, is divided into three phases of Melamchi WSP, in which 170 MLD of water from Melamchi, Larke and Yangri River is adding into the water supply of Kathmandu Valley. It is expected that Melamchi WSP Phase 1, will start from the year 2017, and phase 2 and phase 3 by the year 2022 and 2027 (assumption based on discussion with KUKL official), is represented in results as MSWP Phase 1, 2 and 3, as part of SSM-OWS. Due to the significant impact of all phases, it is represented separately.

The evaluation of individual management scenarios provides an opportunity to experiment the effects of the combination of strategies on overall water supply such as all management option applied at once in WEAP model (named as management option 1—MO1). Results were promising and it encourages to build MO (1–6), with a different combination of strategies to see which one is more effective and practical. After evaluation, the most effective management option, choose to build the four different kinds of future for Kathmandu Valley.

Results and discussion

Reference scenario results

The scenario simulation and analysis of current/reference scenario for water demand results are shown in Fig. 8. The result that in the year 2015 the average water demand coverage in Kathmandu Valley was 19.45% in 2015 and the average daily supply delivered in the valley was 75.5 MLD in 2015. Based on the estimation the future scenarios were modeled and the result showed that the future water demand would be 765.2 MLD (Fig. 7) in the year 2030, which is almost double in comparison of demand data in the base year of the model 2015. The water demands are calculated by considering the factor of domestic water consumption and population growth in the region. The analysis of projections suggests that if there are no changes in the current situation and water supply condition in the valley, the water demand coverage in the valley will decrease to 10–15% in 2030 because of the steadily increased population and henceforth water demand.

The reference scenario projection infers that no improvement in water infrastructure and supply situation will lead the valley into a water-insecure future.

External-driven factor scenario analysis and result

The study formulates externally driven factors that are used to simulate the future scenarios, degree of urbanization, low and high population growth, increase in living standard of the population and climate change. The worst-case scenario is formed with the assumption of no significant improvements in water supply situation, but increase in population growth and high living standard of the population. In the study to analyze the situation where the population growth continue to rise with 6% (high population growth) and most likely with the economic growth, it is possible to increase the living standard of population in the valley and low population scenario that government step up to increase awareness to reduce and able to control

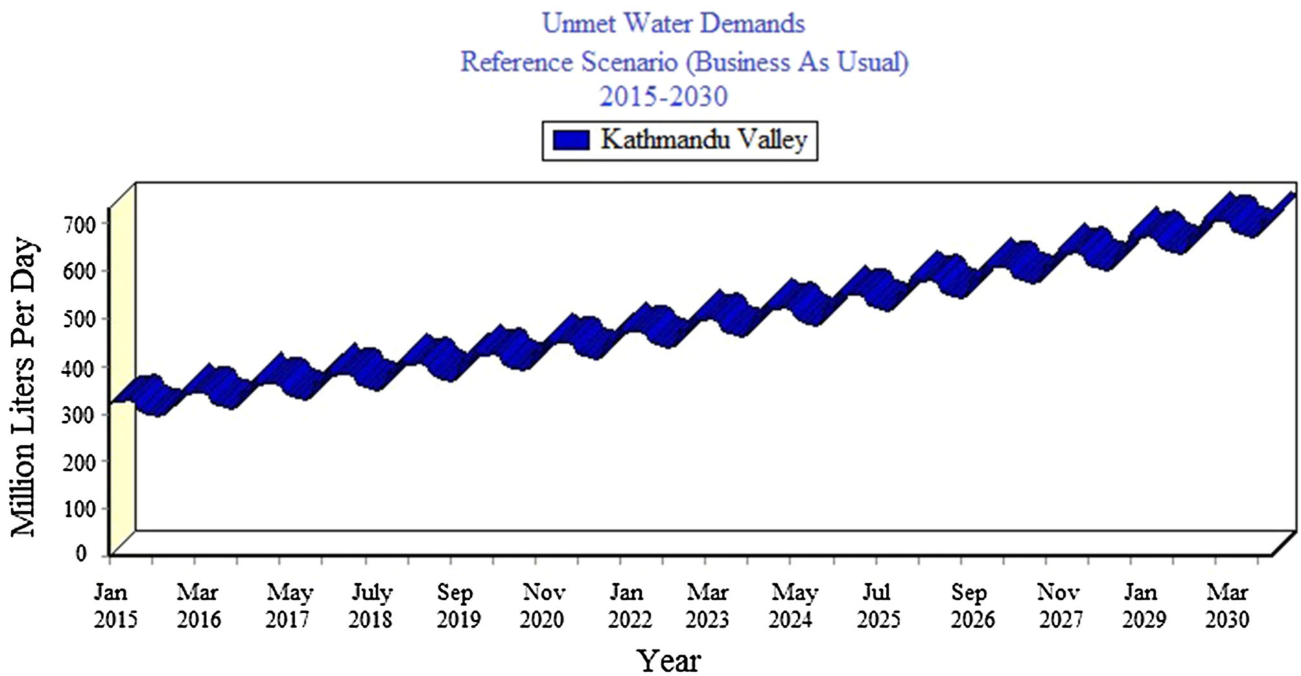

Fig. 7 3D representation of unmet water demand of Kathmandu Valley in reference scenario (2015–2030)

in national growth rate. The domestic water consumption assumed from MWSP (2015) 135 Lpcd in the year 2015 and will increase to 150 Lpcd by the year 2030 (ADB 2013; CIAMP 2010).

The results in Fig. 8a, b show that the except LPG scenario, where the unmet demand is reducing to 415 MLD in April 2030, all other scenarios the unmet water demand is increasing with unprecedented rate, even in the business-as-usual case it will reach to over 700 MLD. As a result, Kathmandu Valley has a scope of improving its water supply capacity if the population growth rate goes down. In HPG scenarios, by the year 2030, the unmet water demand will reach to 940 MLD, which is a serious concern if the water supply is not improved. The higher living standard of the valley is estimated due to the change of economic development pattern and this could lead to unmet water demand by 2030 will be around 790 MLD, population growth increase is 4.63%, which is near to business-as-usual scenario/baseline. To understand the water supply conditions in the worst case, the higher living standards and high population growth scenario (HLS-HPG) water demand will reach to more than 1000 MLD for most of the months for the year 2030 (Fig. 9).

The climate change scenario showed similar trends initially as that of current scenario, but in later stages the demand is growing due to increase in temperature. The study analyzed that in 15 years of study period there is a slight temperature rise in valley will have a negligible impact on water resources. This research can be extended to the deeper analysis of impacts on water systems in the longer term. The situation is expected to worsen worldwide due to the impact of climate change, which will reduce the water supply and increase water demand (IPCC 2007; Null et al. 2010). The results showed that the unmet water demand increased slightly and demand coverage is decreasing with the impact of climate change that too very low, which can consider negligible under other scenarios considered in the study. So the study demonstrated that there is no impact of climate change on this Kathmandu Valley using this RCP 6.0 scenario.

Management scenario results and strategies analysis

The results in Fig. 10 show the comparative analysis of the unmet water demands under the impact of external factors and different management scenarios. It is analyzed that HPG and HLS scenarios have a most negative impact in future on water supply system of Kathmandu Valley. The supply-side management scenario, SSM-OWS, in which Melamchi WSP is functioning and delivered by 2027, reduces the most unmet water demand, around 70 MLD, which seems a good option in short term. The results showed that the effective implementation of proposed MWSP (all phases) will decrease the unmet water demand by 66–56% in the valley. Other supply-side management scenarios such as SSM-WPP, achieve significant positive effect on the system, which leaves sustainable impact and revenue for water authorities to plan ahead, and ‘DSM-

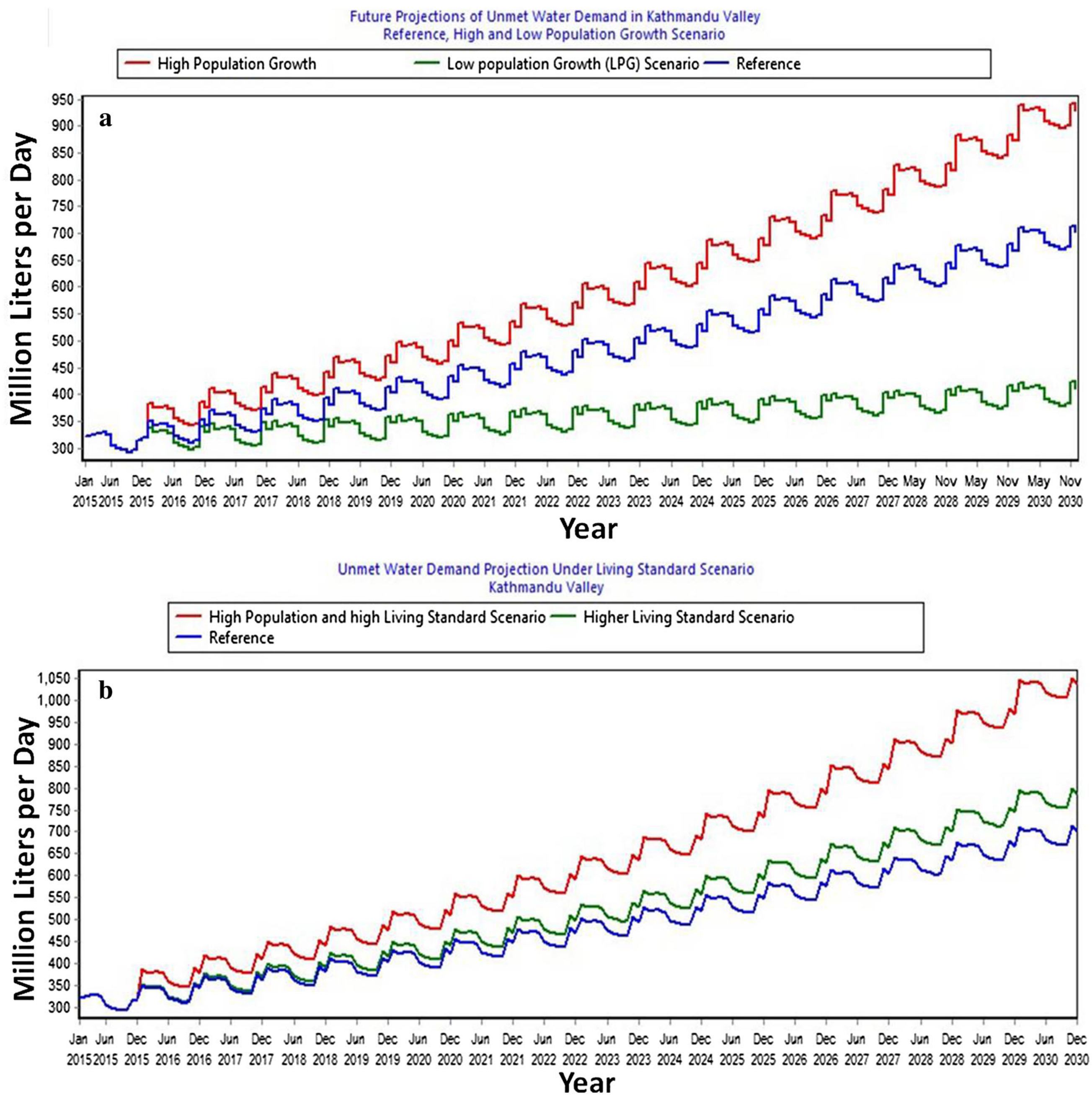

Fig. 8 **a**, **b** Future projection of unmet water demand and high living standard and worst-case scenario in Kathmandu Valley (2015–2030)

ENRW' scenario is very important option to give moderate advantage to the system and will be the best strategy in future by positive impact on water system and environment.

With Fig. 11, it is evaluated that all the management scenarios will leave positive impact on solving the water stress and help the water supply system, but still no one option/strategy able to solve the water crisis completely, in other able to achieve 100% water secure by 2030, which is aim of study. For the same, a different approach is adopted in which new set of strategies are formulated, based on the combination of supply side management (SSM) and demand side management (DSM) strategies. In total six different management options aka strategies are identified based on literature review and previous findings, which are referred as MO1, MO2, MO3, MO4, MO5 and MO6 in the paper. In order to identify the most effective management option or strategy to able to solve the water scarcity in Kathmandu Valley by the year 2030 out of designed MO. The designed management options (MO) are formulated based on the different combination of identified supply and demand side management strategies in above part of the

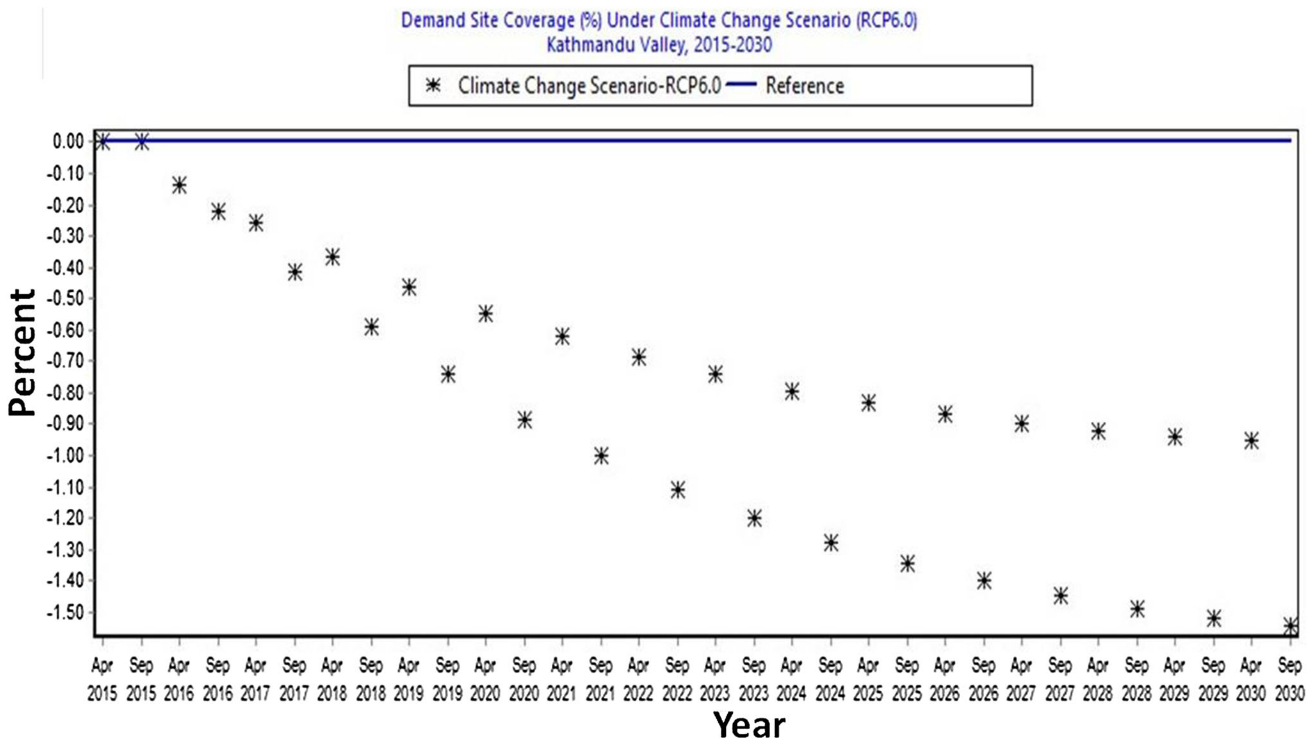

Fig. 9 Future projection of water demand coverage in Kathmandu Valley under climate change scenarios (2015–2030)

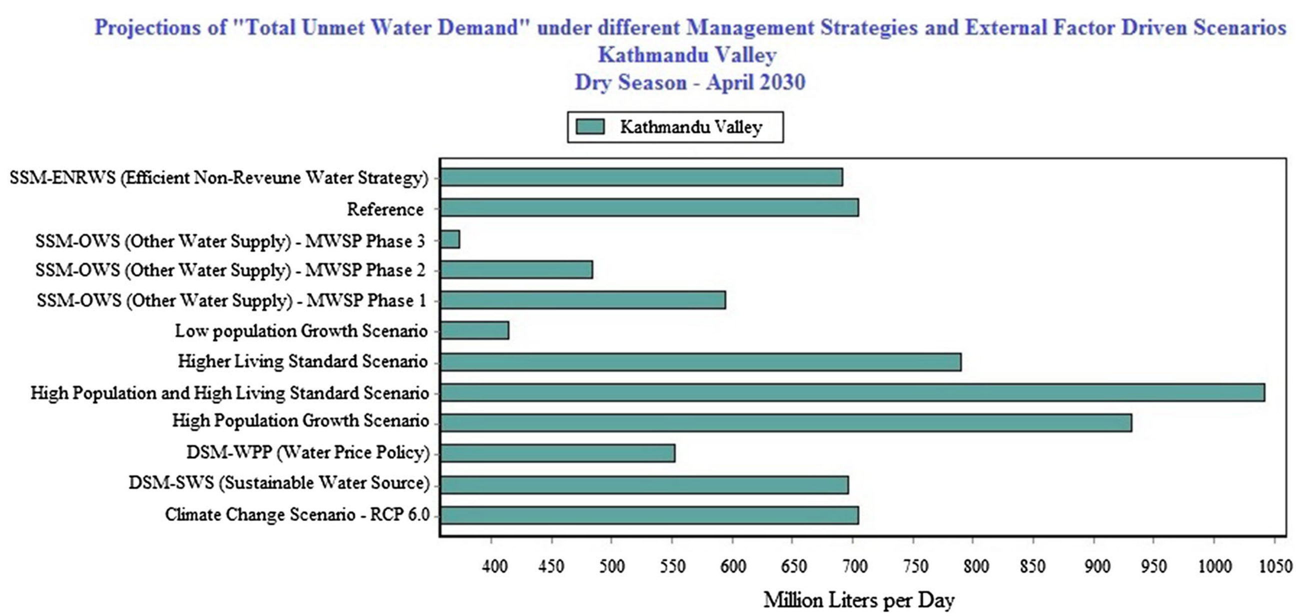

Fig. 10 Comparison of unmet water demands in Kathmandu Valley under different formulated scenarios (April 2030)

paper. The MO1 ('SSM-OWS' + 'SSM-ENRWS' + 'DSM-SWS' + 'DSM-WPP'), management option 1, is formulated with an integration of all supply and demand side strategies as one. The management option 2, MO2 ('SSM-OWS' + 'SSM-ENRWS'), is formulated with only the supply-side management strategies integrated as one, similarly, management option 3, MO3 ('DSM-SWS' + 'DSM-WPP'), is designed integrating only demand side management strategies as one. The MO3 is low cost solution and will be helpful in increasing awareness about water solutions in public. The management option 4, MO4 ('DSM-SWS' + 'DSM-WPP' + 'SSM-OWS'), integrates the supply-side management strategies with only one demand-side management strategy (OWS -

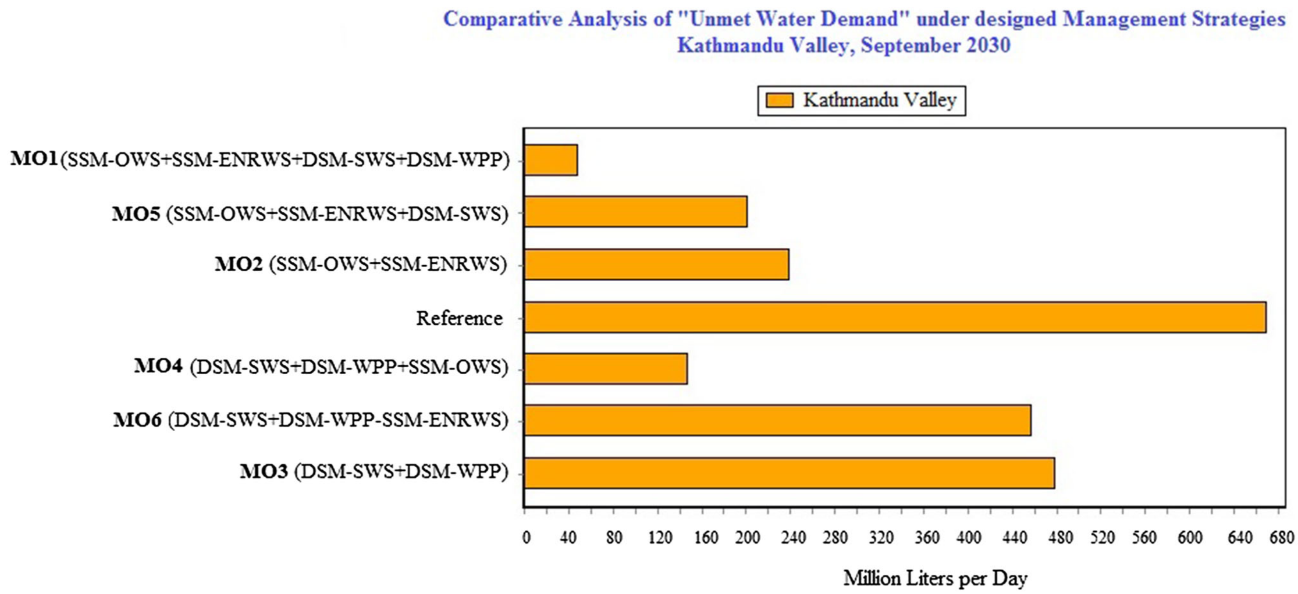

Fig. 11 Comparative analysis of strategies based on unmet water demand in Kathmandu Valley, after integration of management scenario (2015–2030)

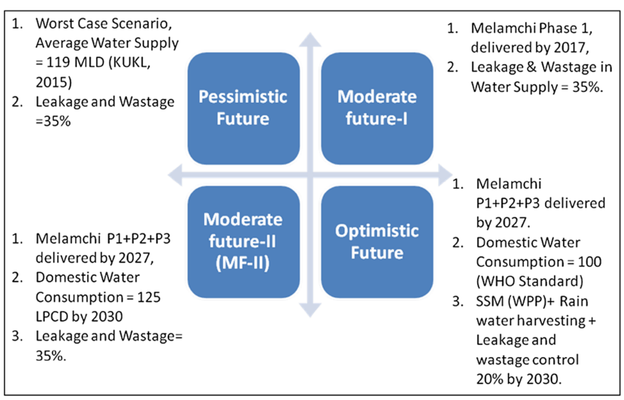

Fig. 12 The future estimation under different strategies of water demand–supply scenario in Kathmandu Valley, Nepal

other water supply source), which is MWSP (Melamchi Water Supply Project) and management option 5, MO5 (‘SSM-OWS’ + ‘SSM-ENRWS’ + ‘DSM-SWS’) is integrating the supply-side management strategies with demand-side sustainable sources, i.e., rainwater harvesting, which is seen as long-term solution to the problem. The management option 6, MO6 (‘DSM-SWS’ + ‘DSM-WPP’ + ‘SSM-ENRWS’), is strategies in which the MWSP projections is not included, this management option is identified in order to understand the importance of MWSP in solve the water crisis on Kathmandu Valley. As MWSP already missed its extended deadlines, in the case these management options (MO1 to MO6) will provide a detailed insight and projection to understand the importance of MWSP and alternative strategies to solve the water scarcity in Kathmandu Vally by 2030. The results (Fig. 12) showed that the MO1, all strategies together, is the most effective and optimal strategy to solve the water stress situation in the city, although all other management options (strategies) will have significant positive impact on water system of Kathmandu Valley. With the use of MO1, unmet water demand in 2030 will be under 60 MLD.

Future Evaluation of Kathmandu Valley

Based on the analysis of scenario and management option the effective management strategies are identified and derived the four possible cases (Shrestha et al. 2015) for future water supply and demand of Kathmandu Valley were analyzed.

(I) Business-as-usual scenario or pessimistic future (PF)

In this scenario, the Melamchi WSP is under construction and due to various reasons unable to start until 2030. The supplied water by KUKL is assumed to be of the same quantity as of now, average supply is 119 MLD (KUKL 2015) and stays same with NRW is 35%. There is loss due to leakage and unaccountable water.

(II) Moderate future-I (MF-I)

Based on the information from KUKL official and information released by Melamchi Water Supply Development Board (MWSDB), MWSP phase 1 will supply water by

2017. In the scenario, MWSP phase is only delivered, which adds to the water supply but NRW is 35%.

(II) Moderate future-II (MF-II)

Based on the information from KUKL official and information released that all phases of Melamchi Water Supply started supplying water by 2027. Similar time, Nepal and city government started campaigning to reduce water consumption and saving water leading to a reduction in domestic water consumption to 125 Lpcd but NRW is 35%.

(II) Optimistic future (OF)

This scenario is formulated considering water is supplied from all three phases of MWSP delivered by 2027, with proper management of water supply distribution networks in place. Additional reservoirs are added to the water network and rainwater harvesting project is also added. The awareness of water conservation in the population is encouraged and implemented by the local and national government. In this scenario, the average water per capita water requirement will be constrained to 100 Lpcd, which is the minimum water requirement as per World Health Organization (WHO) standards. Similarly, the unaccountable water loss is assumed to be reduced from 40 to 20%. Overall this scenario is when MO1 (effective strategy) along with the decrease in domestic water consumption by the year 2030 (Fig. 12).

As shown in Fig. 13a, b, business-as-usual scenario is exerting negative impact on Kathmandu Valley water stress situation, in that the water demands are soaring and will be double by the year 2030. In moderate I and II future, the impact of Melamchi water supply is positive and reducing the water demands significantly, in moderate II future it is reducing almost 280 MLD, in which decrease in domestic consumption plays an important role as well. But the aim of the study was to achieve 100% water security by 2030, which is possible in an optimistic future, where the all suggested strategies and reducing domestic water consumption to WHO level is required.

Discussion

The study presented the analysis of management strategies and future scenarios to be considered in planning and designing sustainable water governance in Kathmandu Valley. In lieu of water scarcity problem, it is difficult to improve the water services, demand–supply ratio or reducing water losses, which requires the suitable changes in water governance and meeting the required water demand of valley. To attain the sustainable water governance the first step is to understand the current water supply system and evaluate the future impacts of external factors associated. Based on available resources, the demand- and supply-side management applied to optimize the water system to achieve better result and decrease in demand. In the paper, a reference scenario is formulated and the current water demand of Kathmandu Valley is estimated 388.10 MLD, which is less than one-third of it, due to which Kathmandu Valley is water scarce currently. The study found that Melamchi WSP implementation is crucial and a necessity to achieve water security in Kathmandu Valley. The results showed that the effective implementation of MWSP will decrease the unmet water demand and without Melamchi project implementation, there is a high possibility of not being able to achieve 100% unmet water demand by 2030. The study, modeling proved that the alternative water supply and management options such as MSWP could be a game changer to attain reliable water supply service in the future. It is also evaluated that the external factors will increase the pressure on the current water supply system and exacerbate the water scarcity situation. But the study found the negligible impact of climate change in the valley during the study period. The results encourage to turn toward management methodology to solve the water crisis in the valley and demand- and supply-side management strategies are applied in research. The various methods in demand- and supply-side management, including MSWP, modeled and based on comparative analysis the effective strategies are identified.

In the research, strategic development options are developed using different combination strategies called as management options (MO1–MO6). The purpose of integration of all different kind of strategies is to discover the ideal solution for achieving water security in the region. According to the results of integrated management scenarios, with possible management option and analysis of plots, the best possible and most optimal strategy identified is the strategy 'Management Option 1', in which all the supply-side and demand-side management strategies implemented together. As analyzed from Fig. 11, only implementing MO1 strategy is able to achieve 100% water demand coverage by the year 2027, after the successful implementation of MWSP phase 3. As we can see in Fig. 14, the conclusive figure explained the steps achieved results derived and proposed solution. First, the analysis of current water supply system of Kathmandu Valley studied, which was followed by input the acquired data to prepare the WEAP model and derives the business-as-usual case or scenario, which worked as a reference point for the comparative analysis.

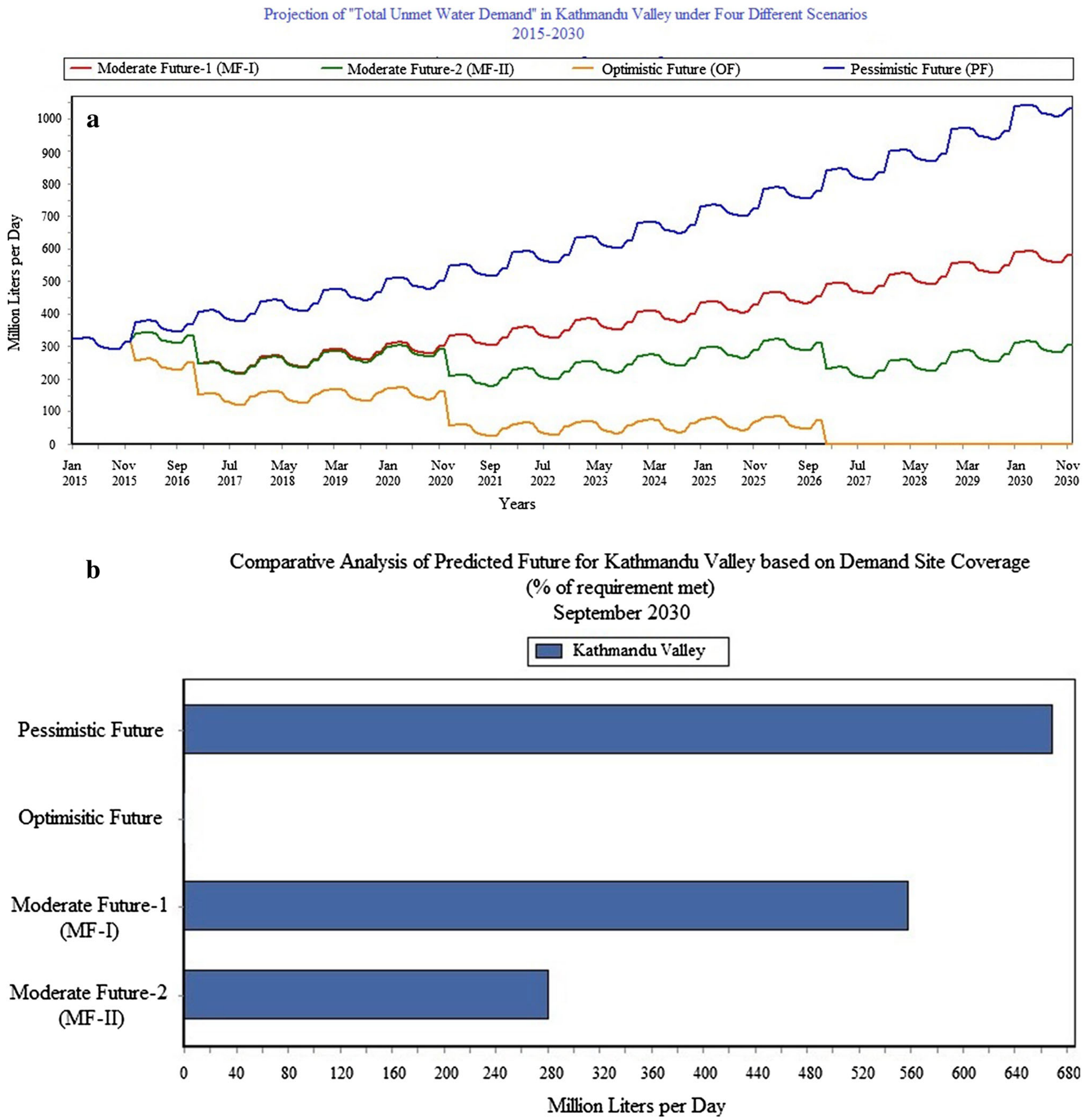

Fig. 13 **a**, **b** Comparative analysis of water demands and demand site coverage of predicted future for Kathmandu Valley (2015–2030)

After that, the scenario designed based on external impacting factors and resources available, led to the formulation of management strategies. The effective management strategies analyzed and recommended and four kinds of futures for Kathmandu Valley were proposed analysis based on that and permutation and the combination of management strategies showed the way to achieve 100% water coverage in the study period of 2015–2030 in Kathmandu Valley.

Recommendations

This study clearly recommended that WEAP is a powerful tool in the evaluation of the current situation and future options in the urban water supply system. This model is based on a well-structured approach that ensures fast model development, ease in precise analysis and flexible in scenarios creation. The tool could assist water planners and policy makers in decision-making for future management

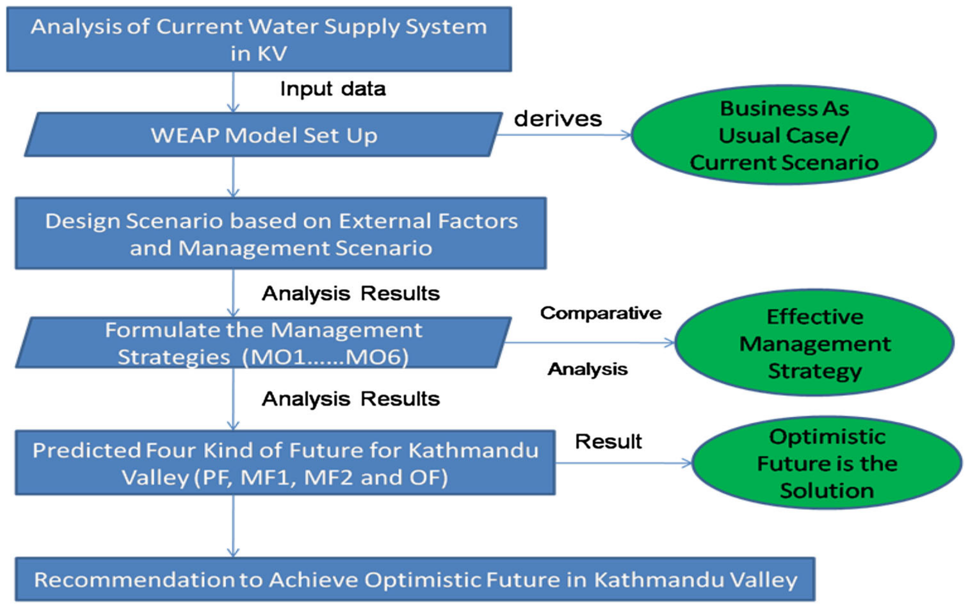

Fig. 14 Conclusive figure explaining the steps achieved and result derived in every stage of the study

of the water supply–demand system. Another advantage of the WEAP model is the support from the developers in terms of publications, tutorial, user guide, the discussion in the user forum and software free support to governmental and academic users from developing countries.

The water quality study of Kathmandu Valley should be integrated with the model by adding water quality data of supply sources to analyze the water quality of the system and model can be used to develop the quality management plan for the urban area. The climate change scenario in this model should need to be expanded considering different future climate change models with different scenarios. The few important and well-known factors are to increase citizen awareness of water's value and culture, building the capacity of water management and environmental protection administration. To address the training needs and facilitate knowledge and exchange of experts information on water governance from water quality to supply management issues at regional and local levels. Based on the study and analysis the important factors on which water managers and local policy maker should focus on, collection and monitoring water data for quantity and quality both, using indicators that adhere to international standards, supporting water research on reducing non-revenue water, including new ways to conserve water and price policies in the valley could bring positive changes, linking research outcomes with policy development, application, and monitoring and establishing fair and socially sensitive valuation and cost recovery. To build the sustainable water governance and achieve the water security, it is recommended to design institutional policy with the participation of the local community in designing strategies mentioned such as RWH harvesting, NRW control plan, and water pricing policy successfully (Ragab 2013). The local authorities should take lead and emphasize on laws and regulations concerning management strategies and educate citizens, increase awareness. The scenarios analysis results and management strategies can be used a starting point of discussion among water planners, decision-makers and local authorities relating to management plans for the improvement of Kathmandu Valley. There is an economic benefit by investing in water efficiency and in comparison to other options, water conservation has been recognized as the cheapest options and can save the largest source of water available within in cities. Reducing the amount of water used in toilets and eliminating leaks in the distribution system are the two most effective approaches to water conservation. Different types of water-saving devices like ultra-low flush, showerheads, taps, washing machines, dishwashers, and urinals are available in the market. These can be the strategies to reduce the domestic water use substantially. However, there is still a lack of awareness among planners, engineers and the general public on the availability and potential of these water-saving devices. The consumers should be made aware that the cost of retrofitting could be recovered in a reasonable period of time from the reduced water bill. These scenario simulations and analysis are useful for local policy planner and water managers for designing the future of water supplies in Kathmandu Valley.

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